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Towards a sustainable mobility as a service: general framework and models' evolution

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Abstract

The evolution of Mobility as a Service (MaaS) and the necessity to achieve sustainability goals, defined by Agenda 2030, impose to build a roadmap for: (i) define a Sustainable MaaS (S-MaaS) able to achieve sustainable goals by taking into consideration the emerging ICTs, (ii) define and develop Transport System Models (TSMs) to support the design of sustainable transport services for ex-ante and ex-post evaluations. This paper aims to address the study of S-MaaS with particular reference to the consolidated methodologies used in the transport systems for the design, management and monitoring of the transport services. The paper presents three main elements: (i) a framework that supports MaaS actors for services design, for demand management and for policies evaluation leaving from the monitoring, in order to implement a S-MaaS; (ii) the identification of the sustainability goals as defined by Agenda 2030; (iii) the methods to analyze passengers' behavior in the presence of MaaS with particular reference to TSMs.

Keywords: Mobility as a Service, Sustainable Transport System, Transport System Models (TSMs).

1. Introduction

The concept of Mobility and Logistics as a Service (MaaS and LaaS, or using a general abbreviation XaaS) has been developing for about a decade in the mobility for passengers and in the movement of goods. This paper refers to MaaS with particular reference to Sustainable MaaS (S-Maas) considering the evolution of MaaS and the need to achieve the sustainability objectives, defined by the 2030 Agenda. According to S-MaaS concept, the transport system needs to be designed to achieve efficient and effective condition, also from a financial and economic point of view, integrating Information and Communication Technologies (ICTs) and Transport System Models (TSMs) in Decision Support System (DSS). The main goals are to design a sustainable transport system. The modelling of this new mode of transport implies the necessity to specify new components of TSMs, as far as concern the travel demand, the transport supply and the demand-supply interaction. This paper considers the technological and communication components crucial for an S-MaaS and it starts from the assumption that the MaaS platform is given.

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The main innovation considered in this paper is relative to the framework of evaluation methods for estimating effects related to the new S-MaaS paradigm. Considering the aim of this paper, three elements are reported. (i) The first element, concerns a framework (section 2) that supports MaaS actors for the design of transport services, the demand management and for the evaluation of intervention policies in order to implement a S-MaaS leaving from monitoring. (ii) The second element concerns (section 3): (ii.1) the sustainability goals (section 3.1) as defined by Agenda 2030, by considering the role of ICT in the development of MaaS; (ii.2) the barriers and constraints (section 3.2) for the implementation of the MaaS and the identification of the measures to overcome them: governance, immaterial, material, equipment. (iii) The third element deals with methods for decision support system for analyzing passengers' behavior in the presence of MaaS. The methods generally rely on TSMs, in particular with the travel demand modelling component. Considering the elements above reported, the paper contains the sections 2, 3 and 4, below described, this introduction and the section 5 with discussions and proposed further developments.

The methodology used begins with an in-depth analysis of the theoretical formulations, practical implementations and legislative regulations, recalling the most important works present in the literature; the next steps are to pass from the detailed analysis to a synthesis of the main evolution framework of the MaaS, with the next step defined by the identification of the limits, barriers and constraints, and opportunities, general DSS, to reach the most advanced levels of the MaaS, S-MaaS, that allow convergence towards the goals of sustainable development.

2. Framework

MaaS integrates and designs transport services considering the users' needs to achieve the sustainability objectives (economic, environmental, social) defined by the United Nations to the 2030 (Filippova and Buchou, 2014). MaaS must be considered at the center of the transport system and transport services must be designed with user needs.

The MaaS was introduced in the last ten years (Hietanen, 2014). Several papers have been published comparing publications regarding MaaS (127 publications in (Maas, 2022) and 90 publications in (Arias-Molinares and Javier, 2023). Several MaaS experiences have been developed in the world (Hensher et al., 2021). The main outcomes are relative to the attractiveness of MaaS, with reference to the urban area, when several separate services and operators are available. Very often the MaaS considers technological integration and innovation. The transport system design, the demand management and the sustainable goals achievement are not a closed aspect and even less the finalization to sustainability goals.

Several classification scales have been proposed for MaaS (Hensher, 2020; Lyons et al., 2019; Sochor et al., 2018). Recently in (Vitetta, 2022), a classification scale has been proposed which considers the evolution of MaaS with respect to the use of technologies (1.0), transport models (2.0), sustainability goals (3.0); each level considers sub-levels within it (Fig. 1). In this paper, the classification reported in (Vitetta, 2022) is adopted evidencing that the levels 2.0 and 3.0 are considered.

The actors involved interact with each other and sometimes have different goals and constraints (more details are given in secs. 3.1 and 3.2). The main actors involved are: people, who can be divided into users of the MaaS system and users of other transport systems; the public authorities which play a decision-taking and making roles from a political point of view and from a technical point of view; the companies who produce the transport and the ICT services supporting the system itself. Analysts support the actors involved in their decisions. Analysts specify, calibrate, and validate models for transportation system analysis and design, and include them in a DSS (Fig. 2).

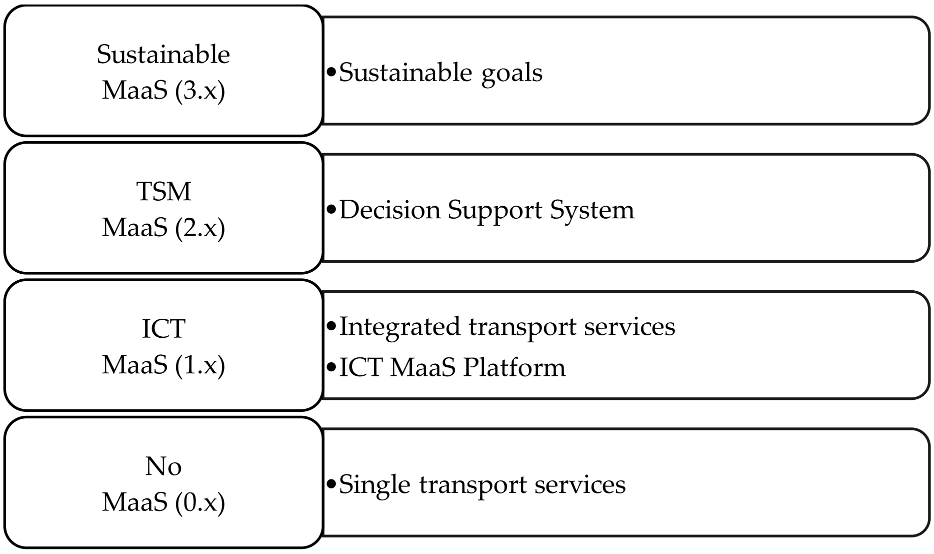

Fig. 1. MaaS levels.

The DSS provides a quantitative assessment to make decisions. It allows the simulation of users' behavior, the evaluation of performance indicators, the design of the best configuration in relation to goals, barriers and technical rules (e.g. laws, guidelines, physical constraints). Decisions are also based on experiences and skills, derived from past experiences and knowledge, and on external decisions. More details are provided in sec. 3 (Fig. 3).

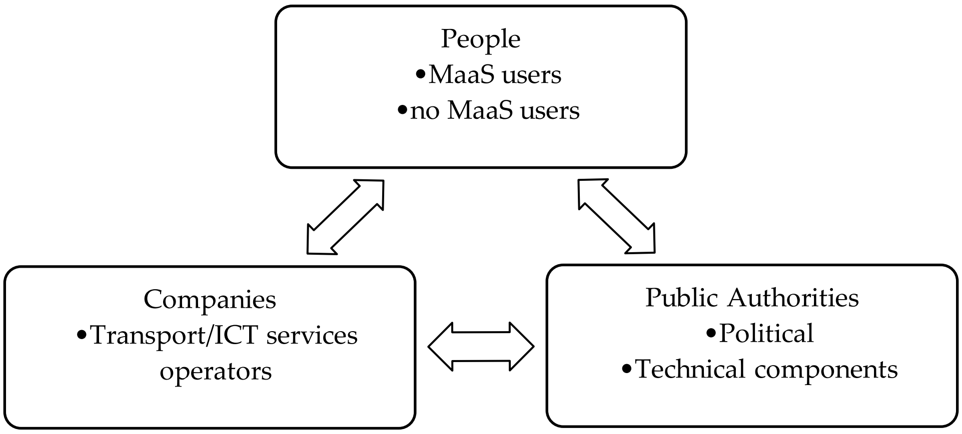

Fig. 2. Interactions among decision takers and makers, analysts.

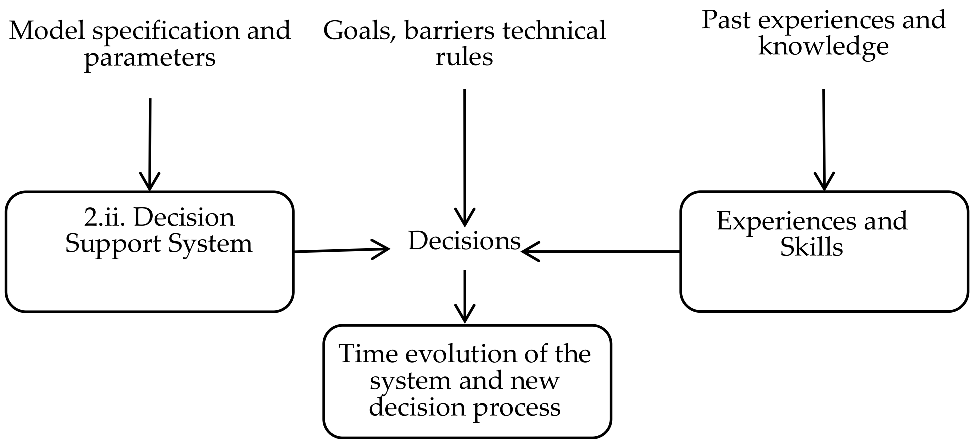

Fig. 3. Decision process.

DSS supports decision makers and decision takers in: planning of supply services and demand management. The models relate to transport demand, supply and demand-supply interaction and allow for the simulation of the transport system in present and designed configurations. The supply services design proposes the best supply configuration in terms of road topology and capacity, MaaS services in terms of topology, frequencies, fares. Demand management offers users the best information in terms of time, destination, service/mode (Fig. 4). More details are provided in sec. 4.

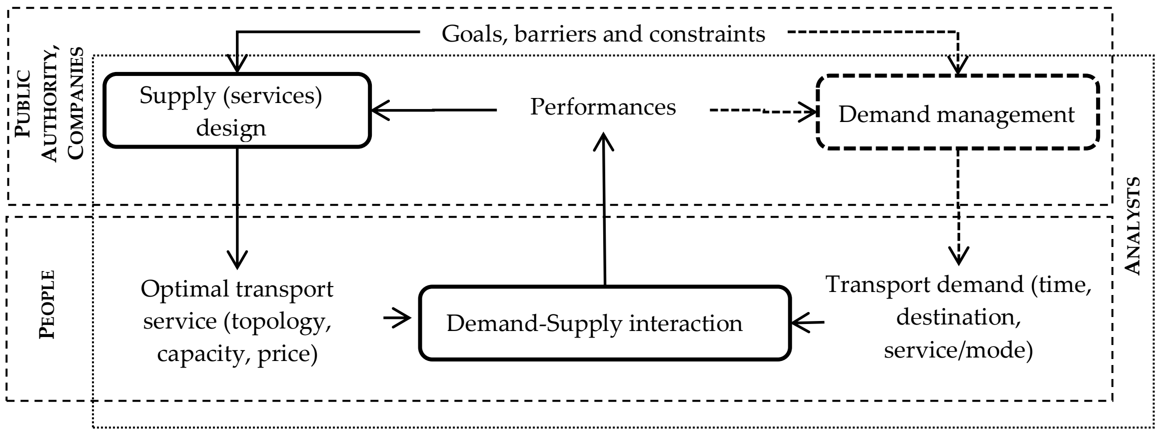

Fig. 4. Methods of Decision Support System

Two pilot surveys of the RP/SP type were carried out to evaluate the preference of the MaaS system in urban, metropolitan and extra-urban areas considering the transport services supported by the technological platform; the RP/SP survey and the resulting statistical and preference probability models expand what is considered in the technology acceptance models. The surveys and the analysis have been conducted by the research team that involves the author and more details are reported in (Musolino et al., 2023) and (Franco and Vitetta, 2023).

In urban (Reggio Calabria, Italy) and metropolitan area (Messina Strait, Italy) a survey of 47 users is considered and a statistical analysis is applied; in extra-urban area (Gioia Tauro area, Italy) a survey of 21 users is considered and a probabilistic preference model is calibrated. The main results obtained are: some users do not leave private car mode; the MaaS preference increases for discontinuity (Birgillito et al., 2018) in origin and destination journeys and for longer journey times; the MaaS preference probability is a high initial value with an additional cost in the current situation (i.e., high parking price).

3. Decision process

The decision process aims at pursuing sustainability goals (par. 3.1) taking into account the barriers and relative constraints (par. 3.2).

3.1 Sustainability goals

The development of MaaS moves in a range defined on the one hand by technological constraints and on the other by the objectives to be pursued.

To date, the main constraint is the progress of the ICT tools available. As far as objectives are concerned, the MaaS study considers the most advanced developments (City of Helsinky, 2019; Reck et al., 2020; Ministro per l'Innovazione Tecnologica e la Transizione Digitale, 2022; Musolino et al., 2022) as the cost optimization component. Therefore, the use of ICT is aimed at better solving the interaction between users and service companies. Other crucial components, such as social and environmental, have not been adequately developed, even if determine the overall development of cities.

Social, economic and environmental impacts are the cornerstones of all sustainable development strategies, as defined in Brutland Report (1987). Since 1987, the international debate on sustainable development has been broad and participatory, leading to the signing in 2015 of the agreements, called Agenda 2030, by 193 countries (United Nations, 2023). The goals defined in 2015 have been associated with specific targets and indicators (see United Nations, 2018). that make it possible to assess the progress of individual countries in sustainable development.

The main issue that arises therefore to the evolution of MaaS is how to move towards more advanced generations of MaaS, compared to those developed to date and which consider only efficiency (Rindone, 2022; Musolino, 2022; Russo and Rindone, 2021; Vitetta, 2022).

The MaaS currently in operation, MaaS 1.0, must complete the integration via ICT of all mobility alternatives available in urban areas, optimizing the efficiency of companies offering mobility services.

The MaaS currently being studied, MaaS 2.0, are those that also manage to improve the utility of the individual user. This generation is developed by integrating the ICT components with the TSM components, mentioned above. The development of this generation is particularly delicate, because it is necessary the presence of a public authority that verifies the information transmitted to the user. Only the public authority can guarantee that there are no distortions in the production and sending of information.

The next generation, MaaS 3.0, whose technical structure is beginning to be defined, will be the one that, in addition to considering efficiency for companies, effectiveness for users, will transparently introduce sustainability related to the 2030 Agenda.

They can be considered three groups of goals of Agenda 2030, which are influenced by interventions in the field of urban mobility (Russo, 2022; Russo, 2021; Russo and Comi, 2023).

The first group is the one that is directly influenced by changes in the structure of urban mobility and whose indicators can be evaluated directly from the outputs of the TSM. Belong to this group the goals: 11 *Make cities and human settlements inclusive, safe, resilient and sustainable*.

The second group is indirectly influenced by changes in the structure of mobility. The value of the indicators can be calculated, starting from the TSM but other models are needed for the ex-ante estimation of the values. To pursue these goals, political choices are necessary that must be made by the public administration itself, but in sectors other than mobility. Belong to this group the goals: 8- *Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all, 9- Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation; 10- Reduce inequality within and among countries*.

The third group is conditioned indicators. In this case the impacts can always be calculated ex-ante through TSM, but the choices are made in other contexts and by public and private decision-makers who have no direct connection with the public administration of reference for the MaaS whose future effects are being analysed. Goals belong to this group: 7- *Ensure access to affordable, reliable, sustainable and modern energy for all*; 13- *Take urgent action to combat climate change and its impacts*.

3.2 Barriers and constraints

The implementation of the MaaS concept implies a set of evolutions in relation to existing material and immaterial asset of the transport and information systems. Collective transport systems are currently governed by a regulatory framework which imposes specific constraints and influences the decision process (see Fig. 2). This represents one of the possible barriers to the MaaS paradigm implementation. For example, in Italy, at regional and local scale, the national regulations establish that a public decision taker (e.g. the Region) plans and programs the asset of Local Public Transport services (LPT); based on their decisions, it assigns LPT to a transport operator. A contract formalizes the relationships between the planning entity and the service provider. The contract imposes certain constraints regarding the characteristics of the services to be produced (itineraries, frequencies, timetables, ...). Despite the desired objectives defined by national legislation, integration between information, transport services and payment modes is still weak. Traditional collective transport services are supplied with fixed characteristics (timetables, routes, fares, …). However, the MaaS implementation requires flexible forms of transport services and information tailored to the users' travel needs.

According to European best practices, the MaaS implementation must begin with the redefinition of rules about the programming and operation of public transport services. Despite MaaS is still at an early stage, the international tendency is to promote public-private cooperation for its fully implementation. This implies the necessity to overcome current barriers that limit public authorities (from municipalities to national government) involved in the MaaS ecosystem (TNO, accessed on 2022), representing constraints for MaaS implementation.

In addition to the rules, it is necessary to rethink the transport system according to the MaaS paradigm, by grouping the potential barriers (Fig. 5):

- governance barriers related to the rules that influence decision makers and takers in defining mobility policies and in transport system planning; rules impose constraints for transport and information operators;
- immaterial barriers related to the characteristics of the available or designed technologies and models; MaaS paradigm imposes the use of TSMs for the ex-ante evaluations, integrated with decision support models (DSS), and monitoring tools (ICT) for ex post evaluations;
- material barriers connected to the physical characteristics of available or designed material transport infrastructures;
- equipment barriers connected to the characteristics of available or designed vehicles, their mutual connections (vehicle to vehicle - V2V), infrastructures (vehicle to infrastructure - V2I), power supply (vehicles electric, hybrid, …) and level of automation.

Barriers become constraints for the actors' decisions, which are not always in line with the high flexibility required by the MaaS paradigm.

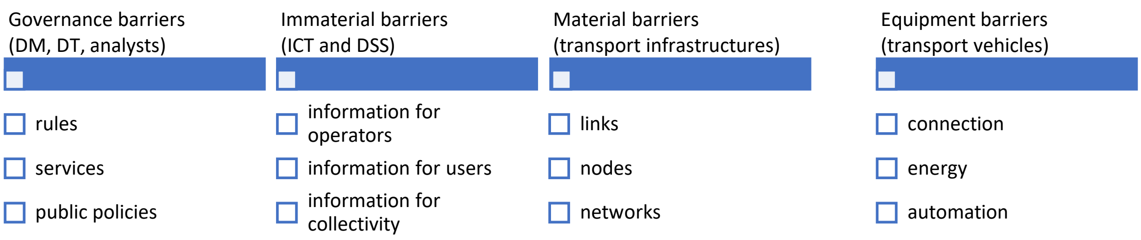

Fig. 5. Classes of barriers (DM, Decision Makers; DT: Decision Takers; DSS: Decision Support System)

4. Methods for Decision Support System

The methods of Decision Support System (Fig. 2-part 2.ii) are based on Transport System Models (TSMs) framework (Ben-Akiva et al., 1985; Ortúzar and Willumsen, 2001, Cascetta, 2013) and references included). TSMs simulate a transport system where the two components of transport supply and travel demand interact. The Supply–Demand interaction model is the core of TSMs and simulates the interaction between the transport demand, expressed by means of users' trip choices (e.g. trip departure time, trip destination and transport service/mode of people) and the transport infrastructures and services, expressed by means of topology, capacity and costs (e.g. travel time, monetary costs). The model estimates the performances of the transport supply (costs) and the flows of people travelling inside the transport system. If the available supply (transport facilities and services) is limited, congestion costs arise (e.g. the travel times increase).

The most common approach of the Supply-Demand interaction models is based on the topological-behavioural paradigm. The topological approach considers the network model, composed of links, nodes and cost functions (Alonso et al., 2019; 2023). The behavioural approach relies on the theory of discrete choice model (Ben-Akiva et al., 1985; Manski, 1977; Train, 2009).

The existing Supply–Demand interaction models can be classified into: static vs. dynamic (Cascetta, 2013; Cantarella, 2019) Static models, mainly equilibrium, operate when it is reasonable to assume that the characteristics of the supply and demand are not far from average levels inside a reference time period. Otherwise, dynamic models are able to capture relevant variations of travel demand flows and of supply capacity. Equilibrium models, such as User Equilibrium (UE) and System Optimum (SO), capture a condition where the users' choices are repeated in the time until an exogenous element, such as a modification in the supply or demand determines a modification in users' choice.

In the behalf of MaaS planning activities, generally operated by public authorities and companies, TSMs are the "engine" able to support the supply (service) design and the demand management. The Supply design models provide an optimal configuration of services (e.g. topology, capacity, costs) according sustainable goals, defined in MaaS of level 3 (see par. 5), and barriers, such as information strategy and incentives (see par. 4), and in line to the performances and the flows of the transport system (Rindone, 2022). The demand management models provide an optimal configuration of travel demand in terms of users' trip choices (e.g. trip departure time, trip destination and transport service/mode of people) according to the goals, previous recalled for the supply design models, and barriers, such as the measures of governance, material, immaterial and of equipment (in terms of modification of level of service attributes). In general, they could support the definition of demand management activities, through the three main classes of measures: information, strategy and incentives (Musolino, 2022).

5. Discussions and further developments

Today MaaS is a reality in different contexts all over the world and several prototypal experiences have also been launched. MaaS cannot be considered just as an integration of existing services and a technology that supports users during pre-trip and en-route travel choices. The system must be designed and managed from the point of view of the user located at the center of the system, also by reorganizing the existing services, considering the sustainability goals defined in the 2030 United Nations agenda.

There are several obstacles to overcome with particular reference to the integration and design of services considered in a unitary perspective, to the management of the system as a whole which involves various public and private decision makers and decision takers and various companies operating in the transport market. The MaaS system must be considered as a new mode of transport, therefore where it is implemented it is necessary to proceed with an a priori scenarios assessment.

For the quantitative evaluations of the new scenarios a valid support is provided by the DSSs, that could support the quantitative estimation of potential effects of a Sustainable MaaS (MaaS of level 3). TSMs are important for S-MaaS planning, as they drive the definition of supply design and demand management activities, through the estimation of trip choices of MaaS (and no-MaaS) travellers and to identify the underlying attributes. A relevant contribution in the development of TSM comes from ICT tools, which are able to collect and process big data within a tolerable elapsed time to capture and model dynamics related to supply-demand interaction patterns.

MaaS paradigm have been implemented in different contexts at global level, together with ICT developments applied to transport. However, it is necessary to consider a set of barriers that are constraints for MaaS implementation. This development aims to pursue efficiency objectives of interest to transport service companies. Only recently there are developments with MaaS 2.0, which also consider the benefit of users. These developments are very delicate if they are not carried out under the control of regulatory authorities. The next frontier is that of MaaS 3.0 which, in addition to the economic objectives of efficiency and effectiveness, considers the pursuit of the objectives of Agenda 2030. This generation is of particular interest. Research developments must be able to allow to estimate ex-ante the results obtainable with respect to the different indicators with the decisions taken by the different subjects.

Future research lines could concern the specification–calibration–validation of parts of TSM in order to capture the effects of the measures of governance, material, immaterial and of equipment, on the supply side; and of information, strategy and incentives, on the demand side, in order to pursue sustainable goal inside S-MaaS.

Author Contributions

Vitetta: general framework and discussion; Russo: sustainable goals and discussions Rindone: barriers, constraints and discussions; Musolino: methods of decision support system and discussions.

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